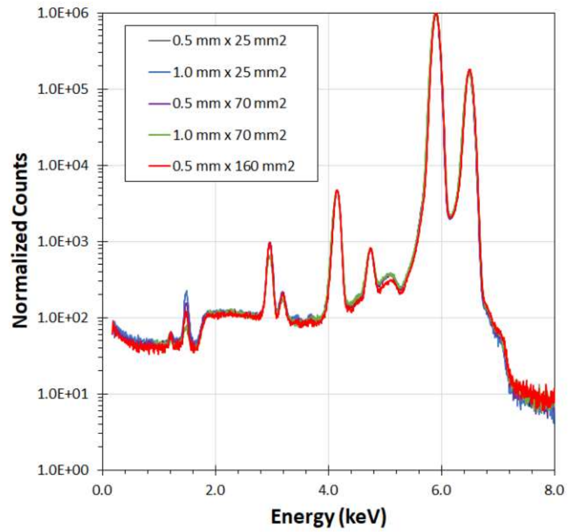
High Sensitivity FASTSDDs

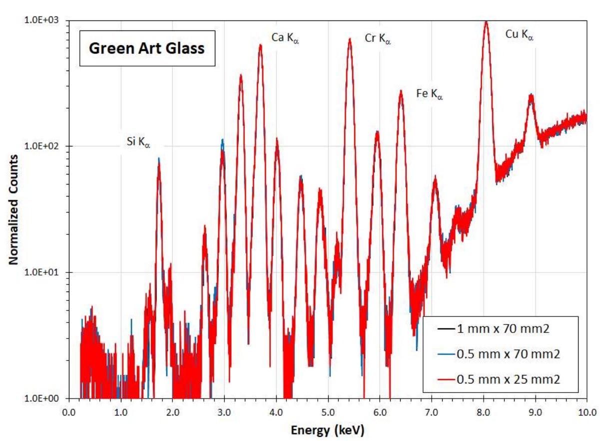
Amptek's FASTSDD® products offer energy resolution near the Fano limit (~123 eV for ^{55}Fe) and operation at high count rates (>1 Mcps). The "standard" FASTSDDs are 0.5 mm thick, with active area of 25 and 70 mm^2. The FASTSDD® is widely used in high performance X-ray spectroscopy, common in X-ray fluorescence, energy dispersive spectroscopy, and related analytical methods in both laboratory and field instruments. Amptek also offers SiPINs, which provide a more economical solution where resolution and count rate requirements are reduced, and CdTe detectors for the higher energy characteristic X-rays.

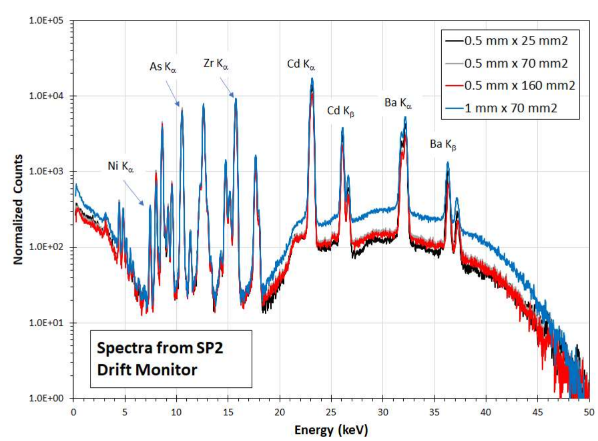
Increasing count rate is very important in X-ray spectroscopy: it improves measurement uncertainty and detection limits[1], and it improves throughput in an instrument. If the X-ray flux is high (i.e. the source is sufficiently strong) then the standard FASTSDD® is adequate and the count rate is largely limited by the signal processing electronics. But there are many applications where the flux is low and the count rate would be improved by a FASTSDD® with larger area or with higher intrinsic efficiency.



Amptek is now releasing several new high sensitivity detectors, with thickness up to 1 mm and area up to 160 mm^2. Unlike prior detector technologies, the energy resolution, electronic noise, and count rate performance are nearly independent of area and thickness. The plot to the right shows normalized ^{55}Fe measured with the different detectors; for all models, the typical resolution is 124 to 126 eV FWHM and the peak to background is >20,000:1.

The plots below show spectra in typical XRF applications. At low energies, the normalized spectra are indistinguishable: the only difference is that count rate is higher with larger areas. As the plot on the right shows, for the 1 mm thick detectors the efficiency improves at energies above 15 keV, improving the detection limits and measurement uncertainties with no compromise at the lower energies.





Though they are all similar, there are some differences in the recommended operating conditions, in performance at the highest count rates, and in other details. This application note outlines these differences.

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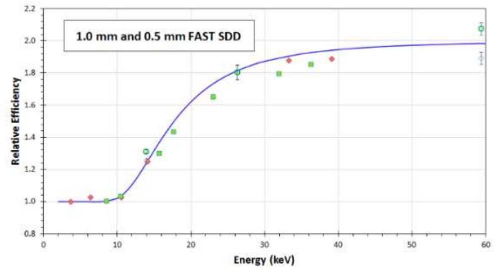
[1] Redus R, Huber A,Dubay R. *Spectrometer configuration and measurement uncertainty in X-ray spectroscopy*. **X-Ray Spectrom**. 2020;1–14. https://doi.org/10. 1002/xrs.3209

Why should I use a high sensitivity FASTSDD®?

- The larger area detectors improve count rates at all energies. So if you need better precision or faster measurements, and you cannot increase the flux from the source, then a larger area will help.
- The 1 mm thick detectors improve count rates only at the higher energies, above 15 keV. The plot shows how efficiency increases in going from a 0.5 to a 1.0 mm thick detector. They are of most use when X-rays are collimated onto a spot on the detector, i.e. when increasing area is not feasible.



- Note that the count rate depends on the solid angle and not just area and thickness. In some applications, the large area detector also allows a larger solid angle, so the flux may increase by more than expected from area alone.

Frequently Asked Questions

Which high sensitivity FASTSDDs are now available?

- The 0.5 mm x 25 mm^2 and 0.5 mm x 70 mm^2 FASTSDDs have been available for many years.
- The 1 mm x 25 mm^2 FASTSDD was released in late 2020.
- The 1 mm x 70 mm^2 and 0.5 mm x 160 mm^2 are now available in pre-production quantities.

Does the energy resolution differ?

- At full cooling and at T_{peak} of 4.0 μs and below, the electronic noise and energy resolution are the same for all of the FASTSDD versions.
- At elevated temperatures and long peaking times, the larger volume detectors have additional electronic noise. They benefit from better cooling and shorter T_{peak}.

What is the maximum count rate?

- The actual "maximum" is poorly defined since it depends on energy resolution; one should really specify the maximum rate for some given energy resolution since both depend on T_{peak}.
- The 1 mm x 25 mm^2 and 1 mm x 70 mm^2 deliver the same count rate performance as the standard 0.5 mm x 25 mm^2 FASTSDD.
- The 0.5 mm x 70 mm^2 and 0.5 mm x 160 mm^2 deliver a slightly lower output count rate, for the same energy resolution. This is due to the longer T_{flat}, discussed in the next item.

Are there differences in the operating conditions?

- The bias voltage must be increased for the thicker detectors. The 1 mm x 25 mm^2 require -400 to -425V, while the 1 mm x 70 mm^2 require -425 to -500V.
- We recommend a longer T_{flat} (a.k.a. gap time) for the 0.5 mm x 70 mm^2 and 0.5 mm x 160 mm^2 to avoid resolution loss from ballistic deficit. Note that the 1 mm detectors use a short T_{flat}.
- Risetime discrimination is not required but will reduce the spectral background in these detectors.

Are there differences in the electrical and mechanical interfaces?

- The electrical interface, voltages, sensitivity, and pinout are the same (expect for the higher bias needed for the 1 mm thick detectors).
- Mechanically, the 1 mm detectors require a package 0.5 mm taller. The 160 mm^2 requires a larger diameter package.

Summary table

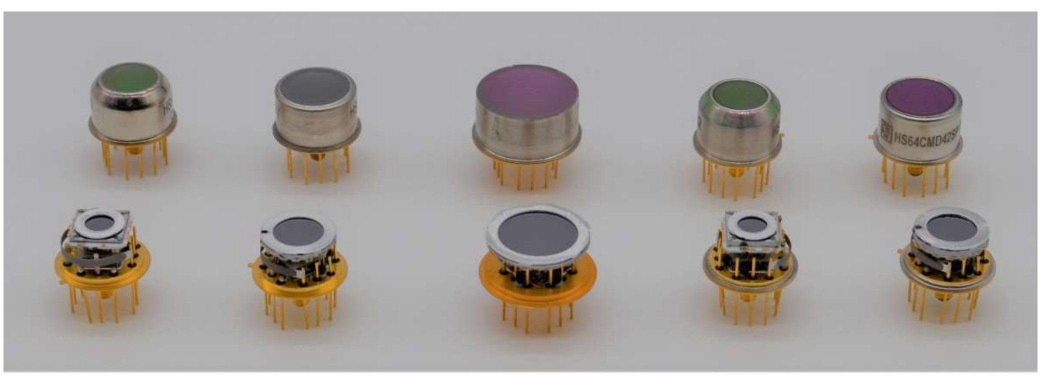
	0.5 mm x 25 mm^2	0.5 mm x 70 mm^2	0.5 mm x 160 mm^2	1.0 mm x 25 mm^2	1.0 mm x 70 mm^2
Thickness (mm)	0.5	0.5	0.5	1.0	1.0
Active area	25	70	160	25	70
Collimated area (mm^2)	17	50	135	17	46
Resolution (^{55}Fe)			Preliminary	Preliminary	Preliminary
T_{peak} = 4 μs, T_{det}=225K	125 eV	126 eV	126 eV	125 eV	126 eV
T_{peak} = 1 μs, T_{det}=235K	127 eV	127 eV	128 eV	127 eV	128 eV
Peak to background	20,000 : 1	20,000 : 1	20,000 : 1	20,000 : 1	20,000 : 1
Count rate example					
T_{peak} = 0.2μs R_{out}	500 kcps	400 kcps	325 kcps	500 kcps	500 kcps
R_{in}	1.3 Mcps	1.1 Mcps	0.9 Mcps	1.3 Mcps	1.3 Mcps
Operating conditions					
T_{flat} (μs)	0.15	0.25	0.35	0.15	0.15
HV bias	-135	-135	-135 to - 180	-400	-400 to -500
Status	Production	Production	Beta units available	Production	Beta units available

Notes

Resolution: These are typical values for the FWHM of the Mn K_α photopeak, at 5.895 keV, measured with ^{55}Fe, at the specified conditions. Please refer to the performance charts for resolution under other conditions.

Peak to background ratio: The "peak to background ratio" is the ratio of counts in the Mn K_α peak channel to the counts at 1 keV, measured at T_{peak}=4 μs and full cooling.

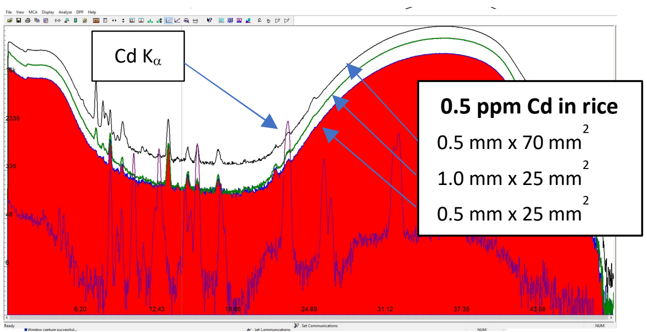
Count rate example: These values do not represent the "maximum count rate" but indicate the maximum input and output rates for a T_{peak} of 0.2 μs and the recommended T_{flat}. At longer T_{peak}, the count rate performance of the units does not differ as much. The ^{55}Fe resolution is similar for all the units. Please refer to the performance charts for further information.



Photos of Amptek FASTSDDs, both sealed (top row) and open (bottom row). From left to right: 0.5 mm x 25 mm^2, 0.5 mm x 70 mm^2, 0.5 mm x 160 mm^2, 1 mm x 25 mm^2, and 1 mm x 70 mm^2.

Advantages of increasing area and/or thickness

How much one gains from a large area and/or thickness always depend on the details of the application, but as a specific example, consider the detection of Cd in rice. In the plot below, a reference spectrum shows the Cd K_α peak. Spectra were then taken from a sample with 0.5 ppm Cd in rice, using a heavily filtered tube at 50 kV, using three of the detectors. The 1 mm x 25 mm^2 has higher counts than the 0.5 mm x 25 mm^2 at higher energies (both peak and background are higher) while the 0.5 mm x 70 mm^2 has higher counts at all energies. The table shows the signal intensity, in cts/sec, and then the relative standard deviation (RSD) of the intensity. The 1 mm x 25 mm^2 detector has an RSD that is 60% that of the 0.5 m x 25 mm^2; the 0.5 mm x 70 mm2 is about 40%; and the 1 mm x 70 mm^2 and 0.5 mm x 160 mm^2 are about 25%. This is a factor of four improvement in the uncertainty, which is quite significant.



	cts/sec for 0.5 ppm			
	Signal	2σ	Rel σ	
0.5 mm x 25 mm^2	0.66	0.17	0.26	Measured
1.0 mm x 25 mm^2	1.01	0.15	0.15	Measured
0.5 mm x 70 mm^2	2.52	0.23	0.09	Measured
1.0 mm x 70 mm^2	3.86	0.23	0.06	Estimated
0.5 mm x 160 mm^2	6.80	0.38	0.06	Estimated

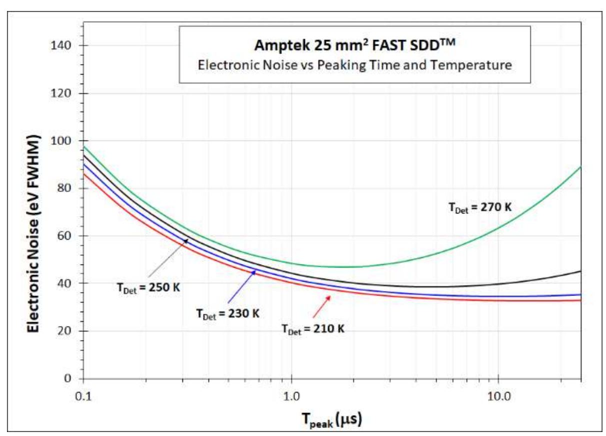
The table to the right estimates the improvement in the detection limit for the different detectors, assuming the same flux and measurement. Note that a low detection limit is desirable. Below 10 keV, it is the area that matters and improves quite a bit with area. Above 25 keV, increasing thickness is also helpful.

	Relative detection limit	
	< 10 keV	> 25 keV
0.5 mm x 25 mm^2	1.00	1.00
1.0 mm x 25 mm^2	1.00	0.71
0.5 mm x 70 mm^2	0.58	0.58
1.0 mm x 70 mm^2	0.58	0.41
0.5 mm x 160 mm^2	0.36	0.36

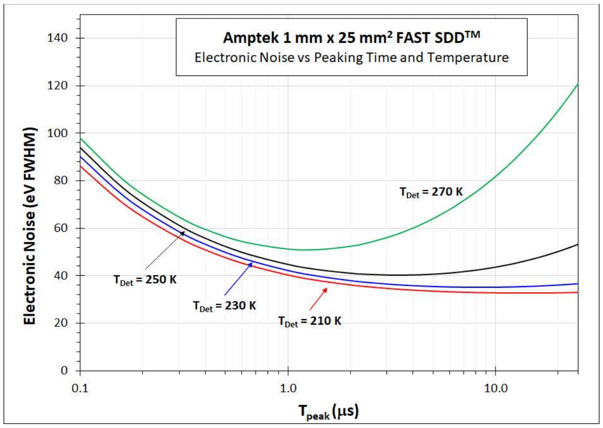
Low detection limit is desirable

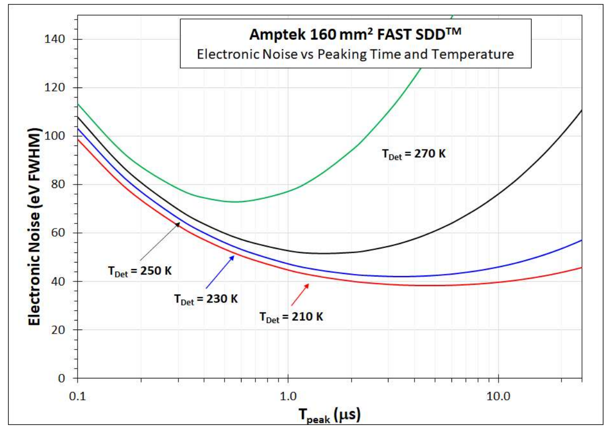
Energy resolution and noise

In all detectors, the electronic noise (and therefore the energy resolution) depends on T_{peak} (the peaking time commanded in the digital processor, which affects maximum output count rate) and on the detector temperature. The plot to the right shows typical curves for Amptek's 0.5 mm x 25 mm^2 FASTSDD®. At full cooling, the minimum noise is at a T_{peak} of > 2µs and the noise does not vary much with temperature below 250K



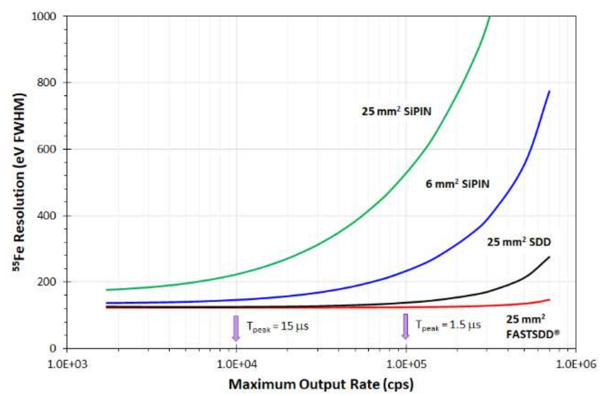
The plots below show typical results for the 1 mm x 25 mm^2 and 0.5 mm x 160 mm^2 FASTSDD® (the 1 mm x 70 mm^2 is similar to the 0.5 mm x 160 mm^2). At T_{peak} < 2 µs and full cooling, the noise is quite similar even for the large area detectors. But at long peaking times and higher temperatures, the larger detectors exhibit more noise. The larger detectors benefit more from the very best cooling. This is due to the fast that, at long T_{peak}, the noise is dominated by shot noise arising from the detector's dark current. Increasing detector volume leads to more dark current and hence more shot noise.



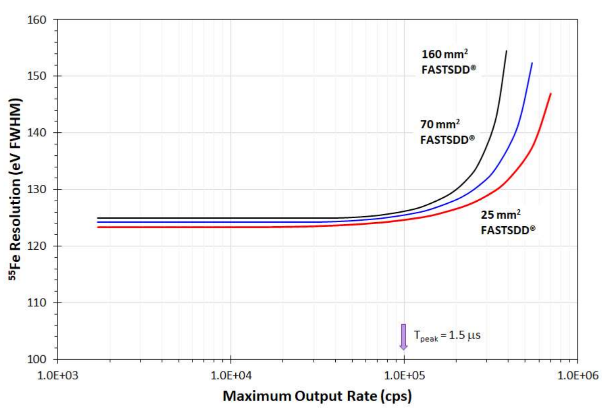


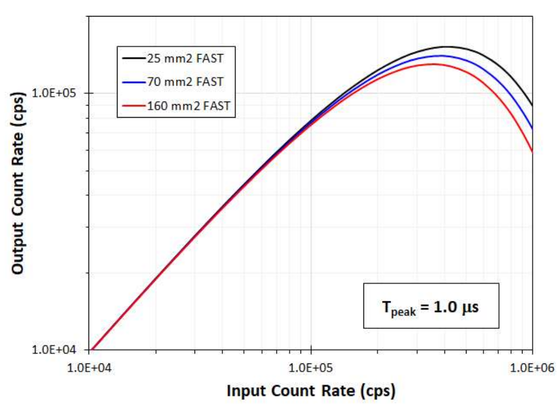
Count rate performance

At short peaking times, the resolution gets worse (as shown in the prior section) but the maximum count rate improves. The plot to the right shows the resolution, at ^{55}Fe, versus maximum count rate (both are implicit functions of the pulse shaping). At low rates, they're not dramatically different - and all the detectors can go to a high rate. There is no "maximum rate." But at high rates, the SiPIN delivers much worse resolution. It is the ability to maintain good resolution at a high output rate that sets the FASTSDD® apart.



The 1 mm x 25 mm² and 1 mm x 70 mm² FASTSDD® have curves identical to that of the 0.5 mm x 25 mm² FASTSDD®. Making the detector thicker does not alter count rate performance. However, the larger area detectors need a longer flat top (a.k.a. gap time) to obtain the best resolution; this increases the dead time per pulse and thus reduces the maximum count rate for a given T_{peak}. The plot on the left below shows the resolution vs count rate for typical 0.5 mm x 70 mm² and 160 mm² detectors and their settings, using Amptek's DPPs. The plot on the right shows the output rate vs input rate for T_{peak}=1.0 µs and the recommended T_{flat} values (using Amptek's DPPs).



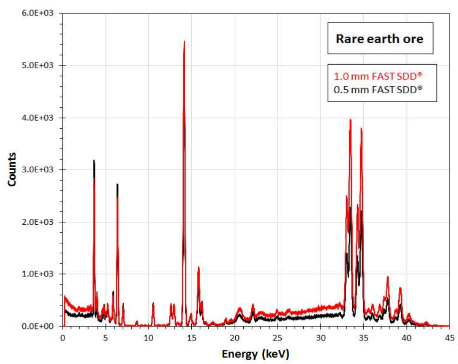


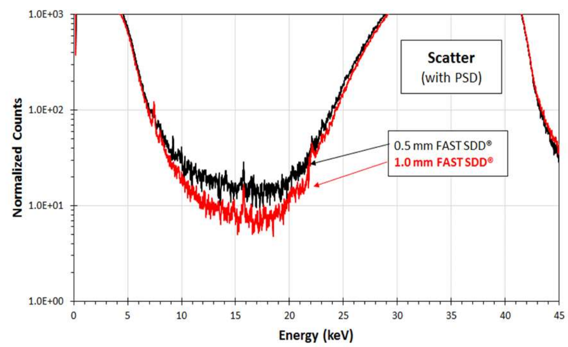
Spectral background

At ^{55}Fe, the spectral background is unchanged among these different detectors. That was shown in the first plot in this note, comparing ^{55}Fe spectra taken with very good statistics with the detectors discussed here, showing that the peak shapes and background intensities are unchanged.

At higher energies, there are some changes to the spectral background. First, in the plot on the left below, the 1 mm detector gives more counts at high energy, as expected. But note that the background is also higher below 5 keV. This can also be seen in the SP2 spectrum shown on page 1 of this note. This is not an artifact of the detector: the probability of Compton scatter is high above 30 keV or so, so some of the X-rays undergo Compton backscatter, depositing only a small portion of their energy in the detector. The increased low energy background arises from the increased Compton scattering in the thick detector.

Second, some X-rays undergo an initial Compton scatter but with the scattered photon absorbed at a different point in the detector. All of the incident energy gets deposited in the detector, but at two different locations and this results in a pulse with lower amplitude, thus adding to spectral background. The pulse also has a slower risetime; Amptek's DPPs implement a "risetime discrimination" (RTD) which vetoes these slow pulses that add to background. As shown in the plot to the right, with RTD the background is actually in the thicker detectors but this is not the case without RTD.





Operating conditions

Bias voltage

The most important difference is that the 1 mm thick detectors require considerably higher bias voltages; the 0.5 mm x 70 and 160 mm^2 will operate at the standard -135V but will deliver faster risetimes (and thus higher output count rates) at higher bias voltages.

- Any SDD has a minimum operating voltage; below this minimum, no signal is collected. It also has a maximum operating voltage; above the maximum, the spectrum is distorted (but no damage is done).
- In the standard 0.5 mm x 25 mm^2 FASTSDD, we recommend -135V and the performance has little variation with bias.
- The 0.5 mm x 70 and 160 mm^2, will operate at -135V and meet noise and other specifications. If the bias is increased, the collecting field is greater, the preamp risetimes faster, and a shorter T_{flat} can be used. The maximum bias voltage will vary from one detector to the next but is typically in the range of -160V to -200V.
- The 1 mm x 25 mm^2 FASTSDD® requires -375 to -400V to operate; the 1 mm x 70 mm^2 FASTSDD® requires -400 to -500V. In these detectors, the noise slightly increases with bias, so operating 25-50V beyond the minimum for operation is best.

Flat top

If T_{flat} is less than the maximum charge collection time, there is a pulse height deficit, termed “ballistic deficit”. This leads to a low-side tail on the photopeaks; it degrades FWHM and makes the peaks non-Gaussian. The effect is worst with a short peaking time.

In the large area detectors, the longer drift time results in longer charge collection times. In the thick detectors, the high bias voltages give a short drift time even with larger area; only the 0.5 mm x 70 mm^2 and 0.5 mm and 160 mm^2 units require a longer flat top. The table on page 2 gives the recommended flat top durations for the various detectors.

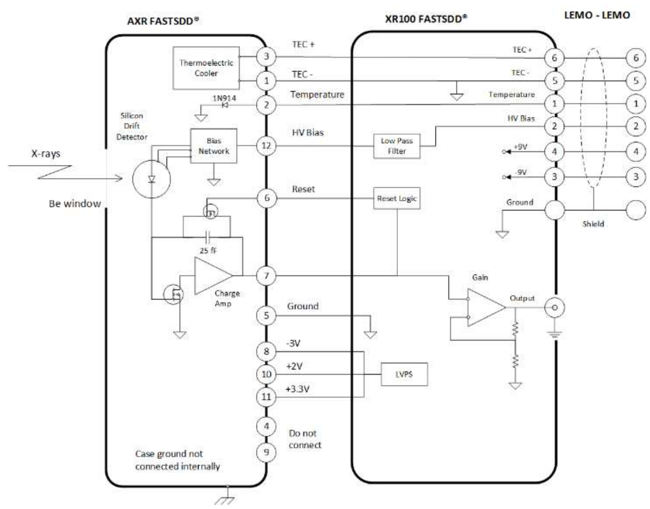
Risetime discrimination

Risetime discrimination (RTD) will reduce background due to Compton scattering in all the SDDs but this is more important in the thicker and larger area detectors. We recommend its use.

Mechanical and electrical interface

Electrical

All of the FASTSDD® variants have the same electrical interface: the plot to the right shows the pinout of the 12 pins on the detector. All FASTSDD® variants have the same pinout and require the same operating voltages (except for bias, as discussed above). The maximum rated voltage to the thermoelectric cooler is the same 3.6V for all the variants, but the 160 mm^2 draws more current at any given voltage.



Mechanical

There are minor changes required to the mechanical interfaces:

- The package for the 1.0 mm x 25 mm^2 FASTSDD® stands 0.5 mm taller than the one for the 0.5 mm x 25 mm^2 FASTSDD®. The 1.0 mm x 25 mm^2 FASTSDD® is only available with a 12 μm Be window and only in the bevel package.
- The package for the 1.0 mm x 70 mm^2 FASTSDD® stands 0.5 mm taller than the one for the 0.5 mm x 70 mm^2 FASTSDD®. The 1.0 mm x 70 mm^2 FASTSDD® is only available with a 12 μm Be window.
- The package for the 0.5 mm x 160 mm^2 FASTSDD® has a larger radius than the others (it will not fit into the standard TO-8 package); the O.D. of the cover is 0.690” while the OD of the header is 0.742”. The 12 pins are at the same locations as for the other FASTSDD® variants so it can plug into the same connections and be used with the same PA-230 preamps. If it is used with an Amptek X-123 or XR-100, there is a small lip on the extended which is removed at the factory; the O.D. of the detector is larger than the O.D. of the extender. It is only available with a 12 μm Be window.

Amptek has detailed mechanical drawings for each of the configurations. Please refer to these for further information.